

Utilization of Agro-food Industry By-products in the Finishing of Culled Dairy Cows: Effects on Meat Quality

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ABSTRACT

This study evaluated the effect of finishing strategies with different agro-industrial by-products on meat quality of culled dairy cows. Culled dairy cows (n = 32) were kept individually and allotted to one of four treatments. A control group (C) was slaughtered immediately after culling-off. All others were subjected to a finishing period of 12 weeks. A forage group was fed with ad lib corn silage (F). Additionally there were a high-energy group (6 kg/day of cassava pulp + ad lib corn silage; F+) and a low-energy group (6 kg/day of crude rice bran + ad lib corn silage; F-) both based on by-products. The longissimus dorsi muscle was excised 24 h post-mortem and stored at -20 °C prior to analysis. There were no significant effects of finishing treatment on meat color of all groups. Drip, thawing and cooking losses were not statistically different between groups. The meat of C had significantly higher percentage of protein and tended to have more moisture than the other groups. Meat of the group F+ had the highest contents of fat and cholesterol. There was no significant effect by treatment on Warner-Bratzler shear force although shear force tended to be lowest with F+. The meat's contents of soluble and insoluble collagen were not significantly different among treatment groups.

Key words: Finishing strategies, Culled dairy cow, Cassava pulp, Rough rice bran, Meat quality

INTRODUCTION

Meat quality includes compositional quality (like lean to fat ratio) and palatability. The major parameters considered in the assessment of meat quality are appearance, juiciness, tenderness and flavor (Lawrie, 1998). Tenderness is one of the most important organoleptic characteristics for consumers judging meat quality. Meat tenderness is depending on muscle characteristics (fiber and collagen properties) at slaughter (Maltin et al., 2003), as determined by genetics and feeding (Wheeler et al., 1997; Sanudo et al., 2004; Andersen et al., 2005), and by animal and meat handling during slaughter and processing.

It is well known that beef from older culled animals is tougher (Bouton et al., 1978) and tend to be drier upon first bite, with a meatiness residue, compared to meat from young animals (Shorthose and Harris, 1990). Hill (1966) found that the effect of collagen on tenderness was due to the soluble part of total collagen, where solubility decreases with increasing age. Several studies have evaluated the efficiency of increasing live and carcass weights of culled dairy cows with high-concentrate diets (Miller et al., 1987; Cranwell et al., 1996; Vestergaard et al., 2007). This improved their condition score and fatness state (Vestergaard et al., 2007). Finishing culled dairy cows can be an important activity to raise the profits of cattle farms, but this requires that costs of feeding in that period are limited. In this study, we therefore were interested in the utility of by-products from the agro-food industry like cassava pulp and rough rice bran. In Thailand, cassava

starch is a large and growing industry generating at least 1 million tons of pulp annually (Sriroth et al., 2000). Cassava pulp is consisting of the solid waste produced by the cassava starch industry. As it still contains high amounts of starch (50-60% of dry matter) it is a feed with a high energy content. Like for cassava, Thailand is one of the world's largest producers of rice. Rice bran is the pericarp and germ of *Oryza sativa* seeds and constitutes about 10% of the whole rice grain. The current main application for cassava pulp and crude rice bran is as a low price animal feed in the beef cattle industry. Therefore, the aim of this study was to investigate the effect of including these by-products into the finishing diets of culled dairy cow son meat quality.

MATERIALS AND METHODS

Animal, housing and treatment

Thirty-two culled Holstein crossbred dairy cows were used in a complete randomized design (CRD). They were penned individually and allotted to one of the four treatments. The control group (C) was slaughtered immediately after culling-off. A forage-only group was fed with *ad libitum* corn silage (F), a high-energy group received 6 kg/day of cassava pulp + *ad libitum* corn silage; F+, and a low-energy group 6 kg/day of crude rice bran + *ad libitum* corn silage; F-. After a preliminary period of 14 days, they were weighed every 2 weeks during 12 weeks. The average initial BW was 447, 427 and 446 kg for three treatments, respectively. Cows were housed at a commercial farm (Chiang Mai Fresh Milk Company, Thailand) and managed following the Animal Care and Use Committee of the Thai Livestock Department following the guidelines of the Federation of Animal Science Societies (1999). The chemical composition and energy value of the feed are shown in Table 1.

Table 1. Ingredient composition (% of DM) of feed used in culled cow feeding trial.

	Corn-silage	Cassava pulp	Rough rice bran
DM (%)	24.8	88.9	87.6
CP (%)	6.79	2.58	5.70
EE (%)	1.35	2.50	4.81
CF (%)	31.2	13.2	12.8
Ash (%)	6.54	3.85	6.20
GE (M cal)	3,655	3,723	3,315
NDF (%)	62.8	37.6	42.1
ADF (%)	36.2	9.80	14.1
ADL (%)	8.67	3.90	4.48

Sample collection and chemical analysis

Feeds offered and left after eating of individual cattle were weighed and collected on two consecutive days of each period (21 days). Samples were taken and dried at 60 °C for 48 h. At the end of the experimental period, feed samples were mixed and sub samples were taken for further chemical analysis. Samples were ground through 1 mm screen and analyzed for chemical analysis. Dry matter (DM) was determined by hot air oven at 105 °C for 6 h. The crude protein (CP) was determined by Kjeldahl analysis (AOAC, 1995). Ether extract (EE) was determined using dichloromethane in a Soxtec System (AOAC, 1995). Ash content was determined by burning in a muffle furnace at 600 °C for 3 h. Gross energy was determine using bomb calorimeter. Fiber fraction, neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined using the method described by Van Soest et al. (1991). The chemical analysis was expressed on the basis of the final DM.

Measurement and sample collection

At the end of the finishing period, the animals were weighed again (final weight). All were slaughtered in a commercial slaughterhouse. The culled cows were transported by truck in the

morning and slaughtered on this evening after a fasting and resting period of 48 h upon arrival. At the slaughterhouse, animal were stunned using a captive bolt stunner and dressed according to commercial practices. Carcasses were split, weighed and then chilled at 4 °C for 24 h before being processed on the day following slaughter.

Assessment of carcass and meat quality as well as chemical analysis

After chilling, a sample was removed from the *Longissimus dorsi* (6th rib to 12th rib). Samples were stored in plastic bags and kept on ice for transfer to the laboratory. There, each LD was cut into equal portions being 2.54 cm thick. These steaks were vacuum-packaged and stored at -20 °C until further analysis. Drip loss was assessed as the proportionate weight loss of a part of one slice of the muscle (175-185 g) that had been suspended in a plastic bag for 24 h at 4 °C. Other samples were defrosted at 2-4 °C for 24 h for determine thawing loss. Samples were grilled at 160 °C by the principle of circulated hot air (model 720, Mara, Taiwan) after a core temperature of 70 °C was reached (directly controlled by the thermocouple tool) and after 5 min of cooling. The steaks were weighed before and after cooking to determine cooking losses. Instrumental color measurements were recorded at 48 h post mortem for L* (lightness), a* (redness) and b* (yellowness) on the exposed cut surface of the LD between 11th and 12th ribs after 1 h of bloom time by using a Minolta Chroma Meter (CR 400 Osaka, Japan). Measures were replicated three times on each steak. One slice was analyzed after mincing in a blender (Moulinex; model DPA1) for the contents of moisture, protein and ether extract according to standard chemical analyses (AOAC, 1995) and then the content of ether extract was calculated and expressed as LD intramuscular fat (g of fat/ 100 g of muscle). The quantification of cholesterol was carried out by the method of Jung et al. (1975) and Biggs et al. (1975), respectively. Meat samples used for Warner-Bratzler shear measurements were first wrapped in aluminum foil and cooked to an internal temperature of 70 °C in a convection oven pre-heated to 200 °C. The sample's internal temperature was monitored with a date logger and a thermocouple probe inserted horizontally at the steak's midpoint. The steaks were allowed to cool to 25 °C before testing. The maximum shear force was determined from five 1.27 cm diameter cores which had been removed parallel to the longitudinal orientation of the muscle fibers. Each core was sheared perpendicular to the direction of the muscle fibers using a texture analyzer (model TA.XT plus, stable micro system, Ltd., London, England).

Statistical analysis

Data were analyzed by ANOVA with GLM procedures of SAS (1996) with treatment as a fixed factor. The least squares mean (LSM) were compared for significance of the difference using Duncan's New Multiple Range Test.

RESULTS AND DISCUSSION

There were no significant effects of finishing treatment on meat color of all groups but meat of the group F+ tended to be of a lighter color than that of the other groups (Table 2). This was possibly related with the higher fat content of the meat. Supporting our results, Muir et al. (1998) found that lean color is associated with increased marbling score. Their investigation showed an effect of short-term feeding of 3-year old steer on lean meat color, with significant effects of concentrate on L* (lightness) and a* (redness) values. In the present study, compared to F, F+ and F- probably had lower carotene concentrations in the meat than corn-silage only fed cows, as the extended feeding of concentrate feeds would have resulted in a lower intake of corn silage. There were detectable effects of increased yellow pigment in fat with increasing grass silage (Strachan et al., 1993) and the same might have been true for maize silage. In addition, Warren et al. (2008) shown that the difference in color intensity gradually developed between a concentrate and a grass silage-fed group, with a lower intensity of the red color found in the concentrate group. These results also agreed with Priolo et al. (2001) who found, in a review of several studies that muscle from grass-fed cattle tended to be darker than those from grain-fed cattle. Conversely, some authors

showed that neither grass nor concentrate diets had effects on the color of the loin muscle from Irish beef (Dunne et al., 2005, 2006; French et al., 2000, 2001). Different from that, Minchin et al. (2009) showed a significant effect of the duration of the feeding period on muscle lightness, but this effect could not be related to diet ingredients. The finishing treatment had no significant effect on drip, thawing and cooking losses (Table 2). These traits are not very susceptible to dietary measures as they are mostly determined by genetics and pre- and post-slaughter treatment.

Table 2. Muscle color and water holding capacity of culled cow meat fed with different diets.

Criteria	C	F	F+	F-	SEM	<i>P</i> -value
Meat color						
L*	35.6	36.3	36.8	36.6	4.45	0.464
a*	15.9	16.2	15.5	16.0	3.04	0.345
b*	10.8	11.9	11	11.3	2.67	0.862
Water holding capacity, %						
Drip loss	3.83	4.25	5.09	5.14	2.74	0.761
Thawing loss	18.9	19	20.7	22.8	19.7	0.837
Cooking loss	22.5	20.2	17.9	22.2	11.8	0.888

C = slaughter immediately after drying-off, F = forage group, F+ = high-energy group and F- = low-energy group

The chemical composition of the meat of cows of the four treatments is shown in Table 3. The meat of the control group had significantly higher percentage of protein and tended to be richer in moisture than that of the other groups. The F+ steaks had by far the highest intramuscular fat content, followed by F- (not significantly different from any other treatment). Accordingly, the muscles varied considerably in composition, and the accumulation of fat obviously was most influential for this variation (Kauffman and St-Pierre, 2001). The increase in total moisture and protein content with resulting decreased in fat content (when expressed as a percentage) intramuscular fat content has been shown to increase with grain (Schaake et al., 1993; Bennett et al., 1995). And it also increased as feeding period increasing (Sawyer et al., 2004). May et al. (1992) observed that marbling score of meat from grain-fed cattle was higher than that of forage-fed cattle only after 84 days on feed. In other studies, forage versus grain feeding had no effect on intramuscular fat content (Vestergaard et al., 2000). The high intramuscular fat content found in F+ confirms that this feeding treatment really supplied extra metabolically available energy as was intended by finishing, while the efficiency of strategies F and F- remained questionable in this respect.

The cholesterol content was affected by finishing treatment in a way that they increased as fat content increased, which implies a direct relationship between fat and cholesterol content of the muscle. Values reported on the cholesterol content of beef have are variable and range from 47 to 114 mg/100 g of fresh meat (Del Vecchio et al., 1955; Kritchevsky and Tepper, 1961). Rule et al. (1997) emphasized that breed, nutrition, and sex do not affect the cholesterol concentration of bovine skeletal muscle. Several investigators have also reported different cholesterol contents of lean and fat, which is consistent with the present findings. However, Feeley et al. (1972) reported that the cholesterol content of lean and separable fat is similar and Tu et al. (1967) reported that the degree of marbling had no effect on muscle. A common serving of beef from pasture-based production systems has low levels of cholesterol (Padre et al., 2007). Jimenez-Colmenero et al. (2001) reported that the consumption of 200 g of beef represented cholesterol intakes of 83, 73 and 81 mg from beef from natural pasture-based Nguni, Bonsmara and Angus, respectively, which corresponds to less than 30% of the recommended maximum daily cholesterol intake 300 mg/day (Greene and Feldman, 1991)

The effect of the finishing treatment on Warner-Bratzler shear force (Table 3) was not significant, but the meat of group F+ tended to be the lowest when compared with the other treatment ($P < 0.1$). By contrast, French et al. (2000) found no difference in WBSF between beef pro-

duced on grass-based and concentrate-based diets. In any case the level of shear force measured in the present study by far exceeded the value of 40 N from where beef is considered tender, a level which can be approached with technical measures postmortem (Jaturasitha et al., 2004). One factor affecting tenderness are changes in the myofibrillar protein structure of the muscle either genetically determined or taking place in the period between animal slaughter and meat composition (Muir et al., 1998).

Table 3. Chemical composition and shear force values of culled cow meat fed with different diets.

Criteria	C	F	F+	F-	SEM	P-value
Chemical composition (%)						
Moisture	72.97	72.51	71.47	71.59	0.764	0.284
Protein	22.31 ^a	21.22 ^b	21.09 ^b	21.63 ^b	0.077	0.001
Fat	3.38 ^b	3.98 ^b	6.69 ^a	4.22 ^{ab}	0.885	0.009
Cholesterol mg/100g	50.04 ^b	61.44 ^{ab}	72.96 ^a	65.39 ^b	59.34	0.043
Shear force (N)	86.37	85.84	77.61	83.49	0.405	0.075
Collagen content (%)						
Soluble	0.263	0.267	0.274	0.272	0.001	0.826
Insoluble	1.045	1.062	1.068	1.043	0.011	0.949
Total	1.308	1.327	1.342	1.312	0.011	0.936

^{a,b}Means within the same row with different superscripts differ significantly ($P < 0.05$)

C = slaughter immediately after drying-off, F = forage group, F+ = high-energy group and F- = low-energy group

Collagen or connective tissue is a second factor that contributes to the toughness of meat. In the present study, there were no significant effects of finishing treatment on contents of soluble, insoluble and total collagen (Table 3). Similarly, Mandell et al. (1998) found that collagen solubility was not affected by diet. Hill (1966) describes that the effect of collagen on tenderness is due to its solubility. Accordingly, Crouse et al. (1985) observed that intact and castrated Angus and Simmental males fed a high-energy diet had a greater amount of soluble collagen than those animals fed a low-energy diet. Longissimus steaks from animals fed a high-energy diet also had a significantly higher percentage of soluble collagen than pasture-fed animals, although total collagen content had not differed (Wu et al., 1981).

A third factor determining tenderness might be given by substantial changes in intramuscular fat content. Wood et al. (1999) stated that a high intramuscular fat content decreased the muscle resistance to shear because of dilution of fibrous protein of soft fat. As Warner-Bratzler shear force decreased in the same treatment where fat content increased, the higher intramuscular fat content may in fact have been responsible for the slight improvement in meat tenderness found. Consistent with that, Vestergaard et al. (2000) found WBSF decreased with increasing intramuscular fat. Also Boleman et al. (1996) found the decreases in WBSF to be accompanied by an increasing of marbling and carcass fatness. However, when animals are slaughtered at similar carcass weights or level of finishing there is no difference in muscle shear force values regardless of diet type (Minchin et al., 2009).

CONCLUSION

This study using agro-industrial byproducts in finishing culled dairy cows to improve meat quality is only efficient when it is a feed with a high energy content. In that case intramuscular fat content and, to some extent, tenderness are increased. The farmer could then sell the culled meat cow as a better quality meat. However, applying additional technological measures like electrical stimulation and CaCl₂ injection may increase palatability and thus meat quality immensely. By contrast, finishing on corn silage either alone or together with rice bran does not seem to be a cost-efficient strategy.

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REFERENCES

- Andersen, H.J., O. Niels, F. Jette, and Y.M. Therkildsen. 2005. Feeding and meat quality – a future approach. *Meat Science* 70: 543-554.
- AOAC. 1995. Official method of analysis. Association of Official Analytical Chemists, Arlington, VA.
- Bennett, L.L., A.C. Hammond, M.J. Williams, W.E. Kunkle, D.D. Johnson, R.L. Preston, and M.F. Miller. 1995. Performance carcass yield and carcass quality characteristics of steers finished on rhizoma peanut (*Arachis glabrata*) -tropical grass pasture or concentrate. *Journal of Animal Science* 73: 1881-1887.
- Biggs, H.G., J.M. Erikson, and W.R. Moorehead. 1975. Annual colorimetric assay of triglycerides in serum. *Clinical Chemistry* 21: 437-441.
- Boleman, S.J., R.K. Miller, M.J. Buyck, H.R. Cross, and J.W. Savell. 1996. Influence of realimentation of mature cows on maturity, color, collagen solubility and sensory characteristics. *Journal of Animal Science* 74: 2187-2194.
- Bouton, P.E., A.L. Ford, P.V. Harris, W.R. Shorthose, D. Ratcliff, and J. H. L. Morgan. 1978. Influence of animal age on the tenderness of beef: muscle differences. *Meat Science* 2: 301-311.
- Cranwell, C.D., J.A. Unruh, J.R. Brethour, and D.D. Simms. 1996. Influence of steroid implants and concentrate feeding on carcass and longissimus muscle sensory and collagen characteristics of cull beef cows. *Journal of Animal Science* 74: 1777-1787.
- Crouse, J.D., H.R. Cross, and S.C. Seideman. 1985. Effects of sex condition, genotype, diet and carcass electrical stimulation on the collagen content and palatability to two bovine muscles. *Journal of Animal Science* 60: 1228-1234.
- Del Vecchio, A., A. Keys, and J.T. Anderson. 1955. Concentration and distribution of cholesterol in muscle and adipose tissue. *Proceedings of the Society for Experimental Biology and Medicine* 90:449-454.
- Dunne, P.G., F.P. O'Mara, F.J. Monahan, P. French, and A.P. Moloney. 2005. Colour of muscle from 18-month-old steers given long term daily exercise. *Meat Science* 71: 219-229.
- Dunne, P.G., F.P. O'Mara, F.J. Monahan, P. French, and A.P. Moloney. 2006. Changes in colour characteristics and pigmentation of subcutaneous adipose tissue and *M. longissimus dorsi* of heifers fed grass, grass silage or concentrate-based diets. *Meat Science* 74: 231-241.
- Federation of Animal Science Societies. 1999. Guidelines for the care and use of agricultural animals in agricultural research and teaching. 1st Review Edition Federation of Animal Science Societies Savoy, IL.
- Feeley, R.M., P.E. Criner, and B.K. Watt. 1972. Cholesterol content of foods. *Journal of the Academy of Nutrition and Dietetics* 61: 134-140.
- French, P., E.G. O'Riordan, F.J. Monahan, P.J. Caffrey, M.T. Mooney, and D.J. Troy. 2000. Meat quality of steers finished on autumn grass, grass silage or concentrate-based diets. *Meat Science* 56: 173-180.
- French, P., E.G. O'Riordan, F.J. Monahan, P.J. Caffrey, M.T. Mooney, and D.J. Troy. 2001. The eating quality of meat of steers fed grass and/or concentrates. *Meat Science* 71: 379-386.
- Greene, J.M., and E.B. Feldman. 1991. Physician's office guide to a lipid lowering diet. *Journal of the American College Nutrition* 10: 443-452.

- Hill, F. 1966. The solubility of intramuscular collagen in meat animals of various ages. *Journal of Food Science* 31: 161-166.
- Jaturasitha, S., P. Thirawong, V. Leangwunta, and M Kreuzer. 2004. Reducing toughness of beef from *Bos indicus* draught steers by injection of calcium chloride: Effect of concentration and time postmortem. *Meat Science* 68: 61-69.
- Jimenez-Colmenero, F., J. Carballo, and S. Cofrades. 2001. Healthier meat and meat products: Their role as functional foods. *Meat Science* 59: 5-13
- Jung, D.H., H.G. Biggs, and W.R. Moorehead. 1975. Colorimetry of serum cholesterol with use of ferric acetate/uranyl acetate and ferrous sulfate/sulfuric acid reagents. *Clinical Chemistry* 21: 1526-1530.
- Kauffman, A.J., and N.R. St-Pierre. 2001. The relationship of milk urea nitrogen to urine nitrogen excretion in holstein and jersey cows. *Journal of dairy science* 84: 2284-2294.
- Kritchevsky, D., and S.A. Tepper. 1961. The free and ester sterol content of various foodstuffs. *Journal of Nutrition* 74: 441-447.
- Lawrie, R. A. 1979. *Meat Science*. 3rd ed. Pergamon Press, Oxford.
- Maltin, C., D. Balcerzak, R. Tilley, and M. Delday. 2003. Determinants of meat quality: tenderness. *Proceedings of the Nutrition Society* 62: 337-347.
- Mandell, I.B., J.G. Buchanan-Smith, and C.P. Campbell. 1998. Effects of forage vs grain feeding on carcass characteristics, fatty acid composition and beef quality in Limousin-cross steers when time on feed is controlled. *Journal of Animal Science* 76: 2619-2630.
- May, S.G., H.G. Dolezal, D.R. Gill, F.K. Ray, and D.S. Buchanan. 1992. Effects of days fed, carcass grade traits, and subcutaneous fat removal on postmortem muscle characteristics and beef palatability. *Journal of Animal Science* 70: 444-453.
- Miller, M.F., H.R. Cross, J.D. Crouse, and T.G. Jenkins. 1987. Effect of feed energy intake on collagen characteristics and muscle quality of mature cows. *Meat Science* 21: 287-293.
- Minchin, W., F. Buckley, D.A. Kenny, F.J. Monahan, L. Shalloo, and M. O'Donovan. 2009. Effect of grass silage and concentrate based finishing strategies on cull dairy cow performance, carcass and meat quality characteristics. *Meat Science* 81: 93-101.
- Muir, P.D., N.B. Smith, G.J. Wallace, G.J. Cruickshank, and D.R. Smith. 1998. The effect of short term grain feeding on live-weight gain and beef quality. *New Zealand Journal of Agricultural Research* 41: 517-526.
- Padre, R.G., J.A Aricetti, S.T.M. Gomes de Goes, F.B. Moreira, and I.N. Prado. 2007. Analysis of fatty acids in Longissimus muscle of steers of different genetic breeds finished in pasture systems. *Livestock Science* 110: 57-63.
- Priolo, A., D. Micol, and J. Agabriel. 2001. Effects of grass feeding systems on ruminant colour and flavour-a review. *Animal Research* 50: 185-200.
- Rule, D.C., M.D. Macneil, and R.E. Short. 1997. Influence of sire growth potential, time on feed, and growing-finishing strategy on cholesterol and fatty acids of ground carcass and Longissimus muscle of beef steers. *Journal of Animal Science* 75: 1525-1533.
- Sanudo, C., E.S. Maciea, J.L. Olletaa, M. Villarroel, B. Paneaa, and P. Albert. 2004. The effects of slaughter weight, breed type and ageing time on beef meat quality using two different texture devices. *Meat Science* 66: 925-932.
- SAS. 1996. *SAS User's Guide: Statistics*. SAS Inst. Inc., Cary. NC.
- Sawyer, J.E., C.P. Mathis, and B. Davis. 2004. Effects of feeding strategy and age on live animal performance, carcass characteristic and economics of short-term feeding programs for culled beef cows. *Journal of Animal Science* 84: 3646-3653.
- Schaake, S.L., G.C. Skelley, E. Halpin, L.W. Grimes, R.B. Brown, D.L. Cross, and C.E. Thompson. 1993. Carcass and meat sensory traits of steers finished on fescue and clover, summer forage, or for different periods in dry lot. *Journal of Animal Science* 71: 3199-3205.
- Shorthose, W.R., and P.V. Harris. 1990. Effect of animal age on the tenderness of selected beef muscles. *Journal of Food Science* 55: 1-8.

- Sriroth, K., C. Rojanaridpiched, V. Vichukit, P. Suriyaphan, and C.G. Oats. 2000. Present situation and future potential of cassava in Thailand. Paper presented at the 6th Regional Cassava Workshop. 21-26 Feb 2000. Ho Chi Minh City, Vietnam.
- Strachan, D.B., A. Yang, and R.D. Dillon. 1993. Effect of grain feeding on fat colour and other carcass characteristics in previously grass-fed *Bos indicus* steers. *Australian Journal of Experimental Agriculture* 33: 269-273.
- Tu, C., W.D. Powrie, and O. Fennema. 1967. Free and esterified cholesterol content of animal muscles and meat products. *Journal of Food Science* 32: 30-34.
- Van Soest, P.J., J.B. Robertson, and B.A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber and nonstarch polysaccharides in relation to animal nutrition. *Dairy Science* 74: 3583-3597.
- Vestergaard, M., M. Therkildsen, P. Henckel, L.R. Jensen, H.R. Anderson, and K. Sejrsen. 2000. Influence of feeding intensity, grazing and finishing feeding on meat and eating quality of young bulls and the relationship between muscle fibre characteristics, fibre fragmentation and meat tenderness. *Meat Science* 54: 187-195.
- Vestergaard, M., N.T. Madsen, H.B. Bligaard, L. Bredahl, P.T. Rasmussen, and H.R. Andersen. 2007. Consequences of two or four months of finishing feeding of culled dry dairy cows on carcass characteristics and technological and sensory meat quality. *Meat Science* 76: 635-643.
- Warren, H.E., N.D. Scollan, G.R. Nute, S.I. Hughes, J.D. Wood, and R.I. Richardson. 2008. Effects of breed and a concentrate or grass silage diet on beef quality in cattle of 3 ages. II: Meat stability and flavor. *Meat Science* 78: 270-278.
- Wheeler, T.L., M. Koohmaraie, and S.D. Shackelford. 1997. Effect of postmortem injection time and postinjection aging time on the calcium-activated tenderization process in beef. *Journal of Animal Science* 75: 2652-2660.
- Wood, J.D., M. Enser, A.V. Fisher, G.R. Nute, R.I. Richardson, and P.R. Sheard. 1999. Manipulating meat quality and composition. *Proceedings of Nutrition Society* 58: 363-370.
- Wu, J.J., C.L. Kastner, M.C. Hunt, D.H. Kropf, and D.M. Allen. 1981. Nutritional effects on beef collagen characteristics and palatability. *Journal of Animal Science* 53: 1256-1261.